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GENETICS of BLACK WALNUT

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Genetics of Black Walnut

by

David T. Funk[1]

INTRODUCTION

The black walnut, *Juglans nigra*,[2] is native to most of the eastern half of the United States and southern Ontario between Lake Huron and Lake Ontario (fig. 1). Over this extensive range the species has adapted to a growing season as short as 140 days in the North and as long as 280 days in the South. Within the black walnut range, annual precipitation ranges from 25 inches in northern Nebraska to 70 inches in the southern Appalachian mountains. Black walnut is sensitive to soil conditions, developing best on deep, moderately well drained, nearly neutral soils that are generally moist and fertile (*20*). On sites with imperfectly drained, poorly aerated subsoils, the rapid early growth of walnut is often sharply reduced after only a few years (*2, 7*).

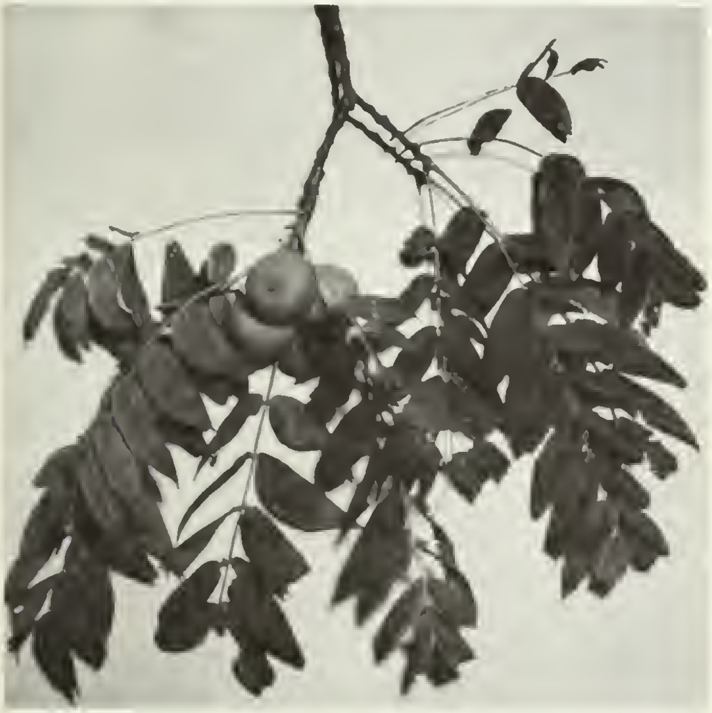
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Figure 1.—Branch tip of black walnut tree, showing compound leaves and cluster of the fruit, a thick fleshy husk covering the thick, hard shelled edible nut.

Despite its relative intolerance to shade, black walnut is often found in climax associations, especially in mesophytic communities. Pure, natural stands of walnut are rare and usually small; it generally occurs as individual trees scattered through the forest. Blewett and Potzger (*5*) show that even though black walnut was sparsely represented in the original forest of central Indiana, the species' longevity gave it an important advantage and it was prominent among the large-size stems. The largest walnut trees in the virgin forest perhaps grew on the west slope of the Appalachian Mountains of North Carolina and Tennessee and in the lower Wabash Valley of Indiana and Illinois (*52*).

Taxonomy

The genus *Juglans* dates well back into Tertiary time, and walnut pollen has been found in numerous locations in Europe where it is not presently native (*44*). Thomsen (*63*) suggests that *J. californica* and *J. hindsii* of modern California may have separated (in approximately their present location) as early as the Miocene epoch.

The Juglandaceae contain five or six genera, only two of which, *Juglans* and *Carya*, are native to North America. *Juglans* is found throughout northern temperate latitudes and extends into the mountainous tropics of Central and South America. The genus has been troublesome for taxonomists who have at various times recognized from as few as 11 to as many as 45 species.

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[2] Tree taxonomy in this paper follows Little (*31*); the authority for scientific names has been omitted.

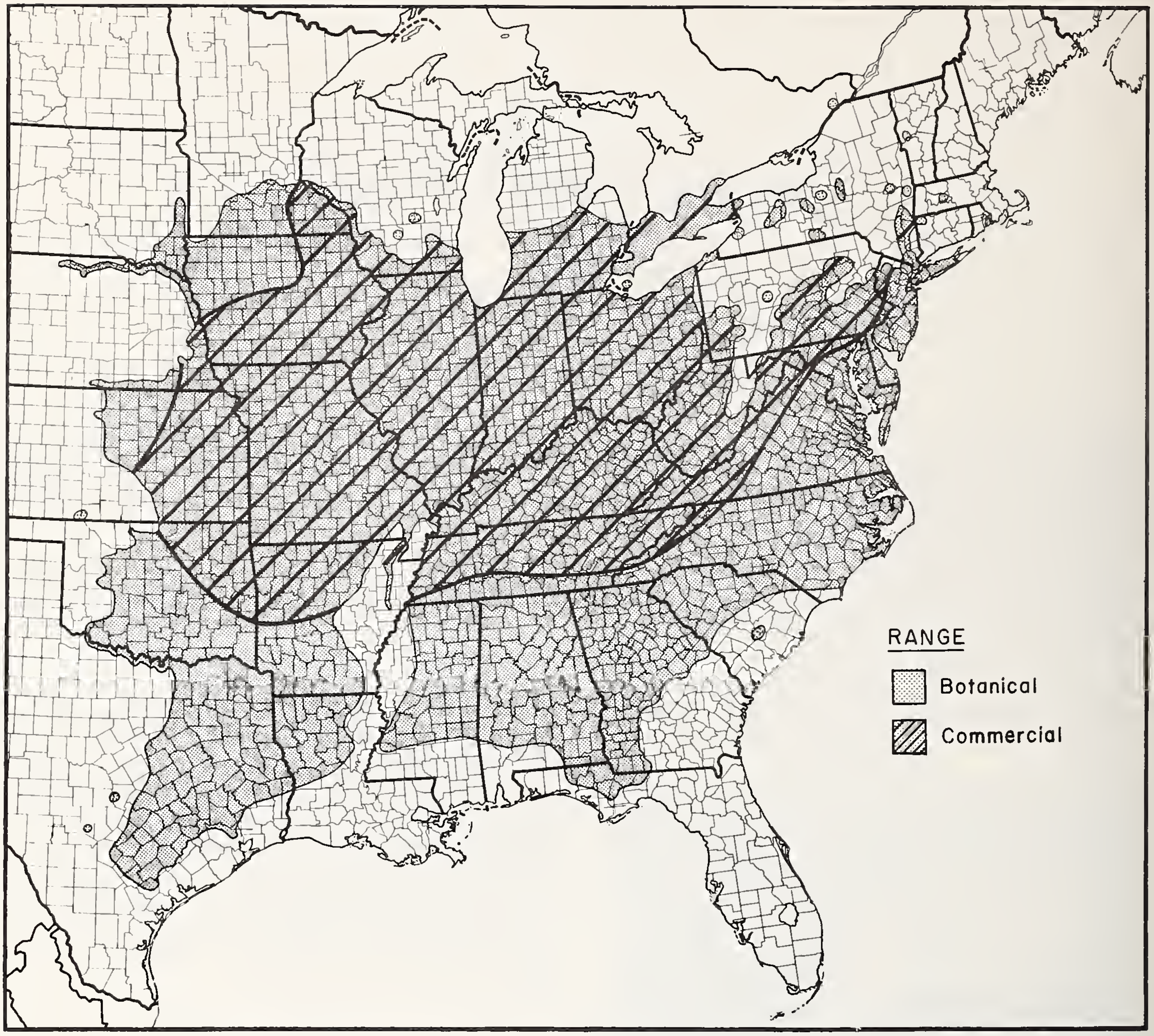
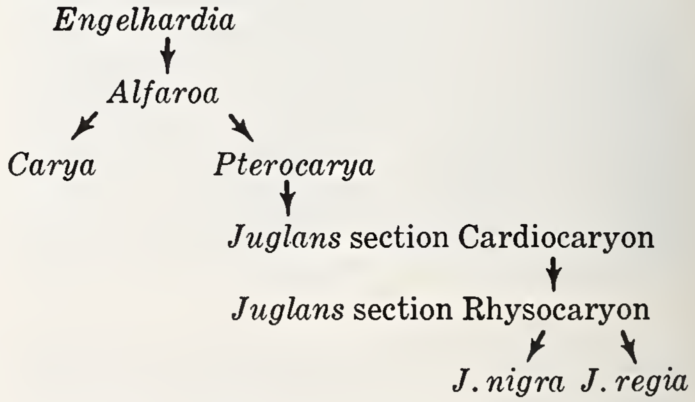


Figure 2.—Botanical and commercial range of *Juglans nigra*.

Although Dode (*16, 17*) divided the walnuts into three sections, most modern taxonomists recognize only two, Rhysocaryon and Cardiocaryon (*40*). All the walnuts in the western hemisphere belong to the subgenus Rhysocaryon except for the butternut, *Juglans cinerea*, a Cardiocaryon walnut. The Cardiocaryon group formerly had a wider distribution including most of North America (*63*). It is now restricted to eastern Asia and eastern North America.

Evolution

Whitehead (*67*) has proposed the following phylogeny for the Juglandaceae:



Whitehead bases his evolutionary sequence on pollen characteristics, with the more primitive walnuts having pollen grains that are

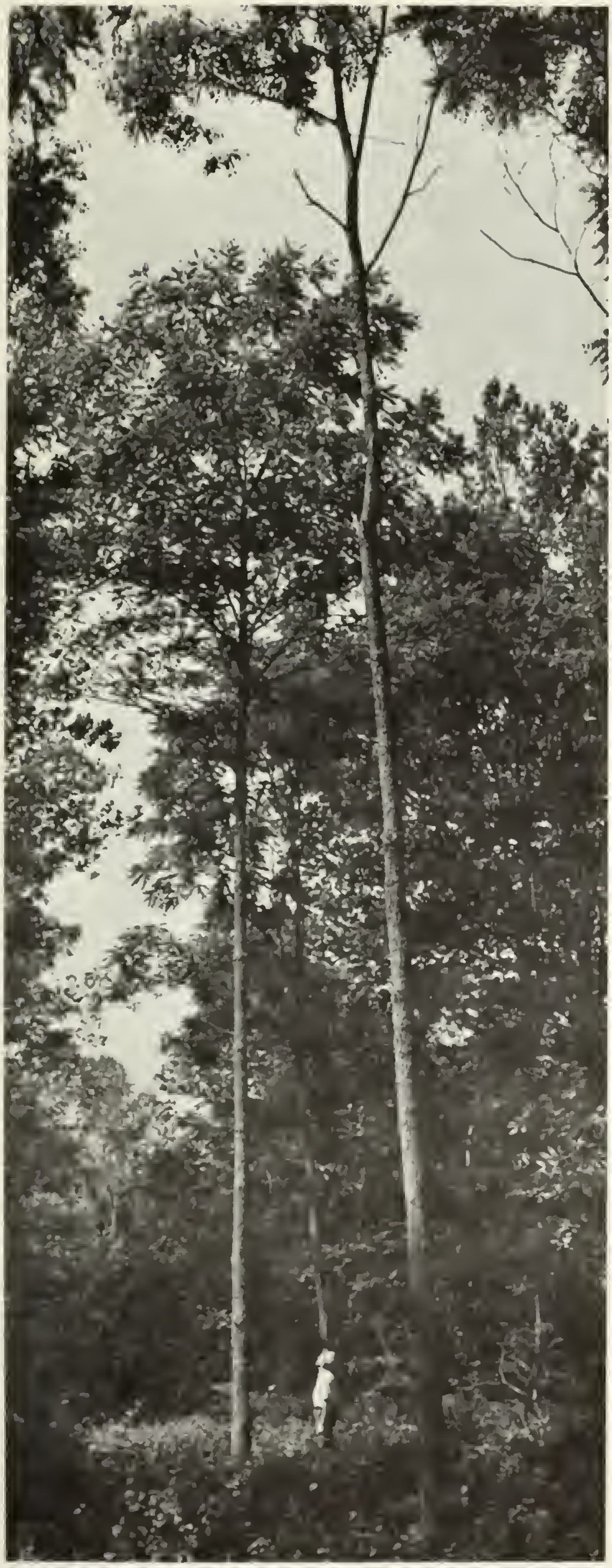


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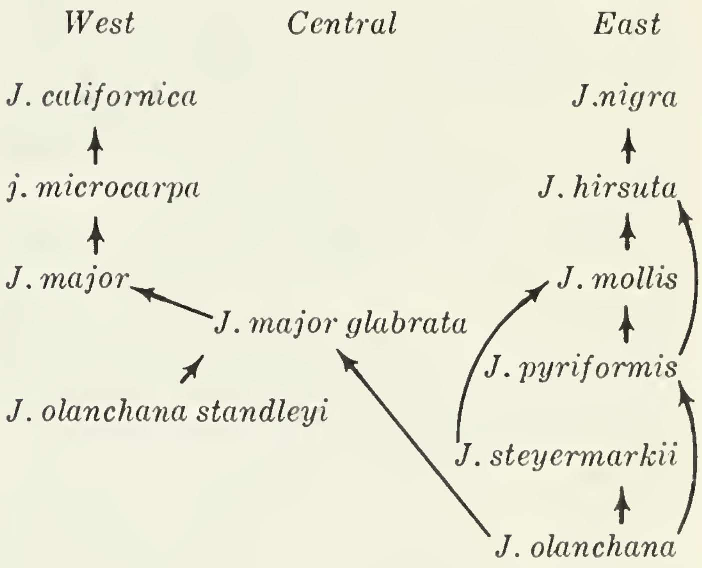
Figure 3.—Two forest-grown black walnut trees, about 30 years old, released for faster growth and pruned for production of high quality veneer logs.

smaller and/or contain fewer pores. The relatively advanced *J. regia* and *J. nigra* have the largest pollen grains and the greatest pore number, respectively.

Manning (*40*)[3] feels that Mexican, U.S., and Canadian walnuts probably evolved from an extinct Central American *Juglans* species, and he outlines parallel evolution and northward migration of three lines of walnuts through eastern, western, and central Mexico:



Range

Physocaryon walnuts in North America are distributed in a notable discontinuous pattern. For instance, the ranges of *Juglans major* and *J. microcarpa*, as described by Sudworth (*60*), meet along the Rio Grande and in southeastern New Mexico, but they do not overlap. Similarly, walnuts in California are always differentiated into geographically separate coastal and montane population. And in Mexico and Central America, "there is almost no overlapping of ranges of the different species." (*40*).

Juglans nigra is also completely separated from the rest of the Rhysocaryon walnuts, although much of the range of black walnut coincides with that of butternut, *J. cinerea*, of section Cardiocaryon. Probably the only place where two species of Rhysocaryon walnuts grow together naturally in the United States is in southwestern Oklahoma where *J. nigra* and *J. microcarpa* ranges overlap in parts of four counties.

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[3] Also letter of February 22, 1966.

SEXUAL REPRODUCTION

Flowering and Fruiting

Black walnut flowers between mid-April and mid-June. Trees in the extreme southern part of the range flower about 7 weeks earlier than those in the North (*30*), but there is as much as a month's variation in flowering dates between individual clones or native trees at one location (*34, 36*). Male flowers are borne on the previous year's branchlets. They are differentiated early in the summer of the year before blooming and the conical male flower buds are apparent by early autumn. Female flowers are borne at the tip of the current year's shoot and often appear before the leaves are fully expanded.

Nearly all walnuts are dichogamous, and protogyny is more common than protandry in *Juglans nigra* (*34*). For most walnut cultivars, dichogamy seems to be more complete in Illinois than in plantations located farther south (*35*). Wood (*72*) reports that young *J. regia* trees are much more subject to dichogamy than old trees, but there is no comparable information for *J. nigra*.

Fertilization follows 2 to 5 days after pollination (*45*), succeeded by development of the inner septum, exocarp, and mesocarp, then the endocarp, and finally the seed itself (*65, 46*). Parthenogenesis sometimes occurs in *Juglans regia* (*72*) but has not been reported for *J. nigra*. Black walnut fruit usually reaches full size in August, ripens in September or October, and drops shortly after the leaves fall, commonly in October (*20*). Newbold[4] collected seed from five trees in southern Illinois at 2-week intervals between mid-August and February; the earliest collection of viable seed was made on August 26. Seed collected between September 10 and January 6 germinated 60 percent or better after 60 days' stratification (seed that floated after hulling were discarded before stratification).

Open-grown black walnut trees may produce flowers and fruit as young as 2 or 3 years of age[5] in the Southern United States, but most do not begin to bear adequately until they are 10 to 12 years old. Grafted trees usually flower within 3 or 4 years after field planting.

No data are available on black walnut pollen dispersion, but Griggs (*25*) states that Persian walnut pollen may travel as far as a mile, although effective natural pollination is generally limited to 200 to 300 feet.

Catkins to provide pollen for artificial pollination should be picked when they are fully elongated and just beginning to shed pollen. The catkins must not be allowed to overheat, and if many catkins are to be collected they should be refrigerated until they can be spread to dry and disperse their pollen under well-ventilated conditions (*25*). Optimum storage conditions for *Juglans sieboldiana* pollen are 0° C. and 40- to 60-percent relative humidity (*12*).

In California, *Juglans regia* pollen viability ranged from 9 to 80 percent and averaged 23 percent (*72*). Optimum conditions for germinating pollen for viability tests are a temperature of 25° to 30° C. and an aqueous medium containing 1-percent agar, 10-percent glucose, and 0.02-percent boric acid (*32*).

Pistillate Persian walnut flowers to be cross-pollinated are bagged after they become visible, but before stigmas become slightly pink and the halves begin to separate (*56*).

Most black walnut trees produce seed in alternate years; only unusual individuals bear an annual crop (*77*). Many large forest-grown trees with long boles and relatively small crowns bear little or no seed for several consecutive years. In contrast, some open-grown trees regularly yield from several hundred to 2,000 to 3,000 nuts per year, with a maximum known production of more than 6,000 seed from a 28-inch-diameter tree in Tennessee (*77*). Among cultivars selected for nut quality, Taft (*62*) reports an average annual yield of 380 seed per tree for 49 ramets of the 'Thomas' variety over a 12-year period from the 9th through the 20th year after planting. Most ramets bore some seed each year, but the general alternate-year pattern was maintained. The total number of bearing ramets ranged from 16 to 46 per year.

Seed Handling and Nursery Practice

Black walnut seed must be stratified if it is to germinate rapidly and completely. It is usually convenient and satisfactory to clean the seed and store it moist in plastic bags. Newbold's best combination of treatments included 60- to 120-days stratification at temperatures alternating daily between 37° and 54° F.[4] Autumn sowing in the nursery is suitable and desirable if rodents can be controlled (*9*). Seed stored dry (at refrigerator temperature) may sometimes retain limited germinative capacity into the second year after collection, but a moist seed usually begins to germinate in the cooler after 6- to 8-months stratification. Properly stratified seed can be expected to complete 75 percent of its total germination within 15 days after sowing.[4]

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[4] Newbold, Ray A. The collection and stratification of black walnut seed. 1967. (M.S. thesis on file at Southern Ill. Univ.)

[5] McDaniel, J. C. personal conversation, August 22, 1967.

Black walnut nursery stock is usually grown and shipped as 1-year seedlings. Planting stock survival and growth are both closely related to seedling size; Williams (*69, 70*) recommends a minimum caliper of 7/32 inch for field planting. Nursery spacing should be no denser than 10 seedlings per square foot if seedlings are to reach this size in one growing season.[6]

ASEXUAL REPRODUCTION

McKay (*38*) summarizes walnut propagation problems as follows:

> Vegetative propagation of black walnut is perhaps more difficult than of any hardwood tree species because of its easily bruised thick bark, excessive bleeding in early spring, and fast oxidation of tannins and other materials in cut surfaces. Attempts to root cuttings of black walnut are generally unsuccessful and other conventional methods of asexual propagation are unreliable.

Good grafting results depend on the use of large-caliper dormant scionwood, usually cut from the basal parts of current shoots or from 2-year-old wood (*38*). Excess sap flow from stock plants is perhaps the greatest hindrance to success when budding or grafting dormant scions (*8*), but cutting stock plants well in advance of grafting to allow them to "dry up" diminishes this problem (*24*). The inlay bark graft as improved by Romberg (*50*) for use with pecans is an efficient technique suitable for walnut grafting when the stock is larger than the scion.

Budding is easier than grafting *(14, 28, 42)* and offers a good chance for economy in large operations (*78*). Growing-season budding avoids most of the problems of stock bleeding and bud drowning (*15*).

Juglans nigra cuttings have been virtually impossible to root, although Hess[7] rooted 2 to 5 percent of softwood cuttings from black walnut seedlings and Lynn and Hartman (*33*) rooted 53 to 70 percent of similar cuttings of the 'Paradox' hybrid (*J. hindsii* x *J. regia*). Better results with layering (*43, 55, 71*) indicate the potential for propagation by cuttings. Hess[8] suggests that an imbalance of endogenous growth substances may contribute to poor root initiation in cuttings, and Gesto *et al.* (*23*) have shown that Persian walnut cuttings contain at least three phenolic acids with weak growth-stimulating properties and two other acidic constituents that were strong growth inhibitors.

GENETICS AND BREEDING

Cytogenetics

Cytologists generally agree that all walnuts have a diploid chromosome number of 32 (*64, 73*), and McKay and McKay (*39*) also found $2n=32$ for *Juglans intermedia*, an apparent natural hybrid between *J. nigra* and *J. regia*. Meiosis was highly irregular in this hybrid.

Repeated attempts to produce amphidiploids by colchicine treatment of sterile hybrids have proved unsuccessful.[9]

Natural Variation

Racial Variation

Emerson (*18*) described a 7-year-old provenance study in Nebraska including black walnut collections from 18 States. Differences in date of autumn leaf drop, twig maturation, and degree of winter dieback were related to latitude of origin. Trees of southern provenance held their leaves later in the fall and suffered more cold injury than those from northern States or Canada. All sources were equally susceptible to late spring frost injury.

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[6] Williams, Robert D. Black walnut nursery practices manuscript.

[7] Hess, Charles E. The vegetative propagation of black walnut (*Juglans nigra* L.). A report of research conducted under Cooperative Agreement Supplement No. 16 to the Master Memorandum of Understanding of June 1, 1953, between the Forest Service and the Purdue Agricultural Experiment Station, Contract No. A9fs-12234, 11 p.

[8] Hess, Charles E. Proposal for a Grant for Basic Forestry Research, October 1965, FS 1 4-10 (WO) (GR), FS-WO-1404 (GR), 12 p.

[9] McKay, John W. Personal conversation, February 1966.

Wright (*74*) suggested that genetic variation in black walnut growth rate involves not only broad geographic races but also local raciation and individual parent tree variation. His study, based on twenty-eight 3-year-old progenies from 18 States grown in Indiana, also demonstrated pronounced "racial" variation in autumn leaf retention. He also found significant differences in 3-year height that were related to region of seed origin. Trees from the South (190 to 200 frost-free days) averaged 16.0 inches tall, while those from the Central Region (160 to 180 days) were 13.5 inches tall and those from the Northwest (150 to 155 days) averaged 14.0 inches. There was no correlation between height and seed weight and no correlation between survival and seed weight, origin, or growth rate.

In a nursery study of 480 *Juglans nigra* families from 80 sources in 21 States, Bey (*4*) found predominantly clinal variation for such traits as height: leaf-length ratio, date of leaf drop, and seedling height. Leaf color was an exception to the continuous variation pattern with a distinct southeastern ecotype differentiated from the rest of the population.

Individual Tree Variation

Flowering phenology is sharply differentiated in individual black walnut trees. The numerous examples of both protogyny and protandry within the same stand have obvious evolutionary significance since this reciprocal dichogamy strongly promotes outcrossing. It seems reasonable to assume that natural selection might favor heterozygosity among genes controlling dichogamy. Rovskii's (*51*) observation of protandry and protogyny within the same seedling family lends some support to this hypothesis.

Seed weight, kernel percent, and crackability vary widely among black walnut varieties selected for nut quality (*76*). Other *Juglans nigra* varieties have been selected for distinctive foliage, including the "Cut Leaf Black Walnut" (*49*) and the "Deming Purple Walnut." Zarger (*76*) recorded pronounced varietal differences in grafting and budding success of 90 *J. nigra* selections tested by the Tennessee Valley Authority, and Maurer (*42*) found differences in rooting capacity of 300 walnut selections layered in stool beds. I have also noted a variation in autumn leaf retention among eight families that originated within a few miles of each other in southern Michigan. The mean number of leaflets retained in early October ranged from less than 3 to more than 20 per year-old seedling (Funk, unpublished).

There may also be good prospects for selection for tree-to-tree variation in cold resistance in black walnut. Shchepot'ev (*58*) reports winter-hardiness in *Juglans regia* in the Ukraine increasing from about 30 percent among 800 selected parent trees to 95 percent among 4,000 seedlings selected from progeny of these parents.

In a trial of 14 open-pollinated black walnut progeny collections in northern Indiana, the mean height ranged from 2.8 feet for the tallest family to 1.6 feet for the shortest of the same age after 3 years. In the entire test, including 40 progenies established over a period of 3 years, families from Arkansas and Missouri were generally taller than those collected farther to the north and east (Funk, unpublished).

Interactions Between Family and Source Variation

In Bey's (*4*) comprehensive study, source variation was 3 to 5 times greater than family variation for most characters studied, though the ratio is as high as 30:1 for date of autumn leaf drop. For height:leaf length ratio, an indicator of apical dominance, a distinct clinal pattern emerged, with southern sources showing relatively greater ratios than northern sources after one growing season in the nursery. Source variance for height:leaf length ratio was about 9 times as great as family variance, and narrow-sense heritability based on variance components was .42. Seventeen families from six sources were held for a second year's study in the nursery; after two growing seasons the height: leaf-length value for the most southern source was 1.5 times as great as that for the most northern source and the value for the "best" of the 17 families was 2.3 times as great as that of the "worst."

In the same study, a greater proportion of the total variance in seedling diameter was related to family variance (vs. geographic origin variance) than was the case with seedling height. Bey (*4*) suggests that height growth is more closely daylength controlled while diameter growth continues later into the fall with inter-source differences in diameter becoming smaller. Finally, family variance for seed weight was more than 3 times as large as source variance.

Hybridization

Only two interspecies hybrids involving *Juglans nigra* have been authenticated, those with *J. regia* and *J. hindsii*. The hybrid with *J. regia* was first described by Carriere in 1863 (*47*). Several forms of this hybrid have been given varietal names, usually based on nut shape (*48*). However, black x Persian walnut hybrids are not at all common in nature, partly because *J. regia* usually flowers about 2 weeks earlier than *J. nigra*, and also because of apparent incompatibility. For instance, McKay (*36*) was able to produce only 12 seeds from 5,000 controlled pollinations using Persian walnut pollen on black walnut staminate flowers. Some *J. regia* x *nigra* hybrids, such as the vigorous 17-year-old trees described by Wellington (*66*), flower profusely but never bear much seed. Often the seed produced does not germinate well, averaging only 27 percent for 19 lots of seed from open-pollinated *J. regia* x *nigra* hybrids in a nursery test (Funk, unpublished).

In addition to having hybrid vigor (*36*), some Persian x black walnut hybrids are more winterhardy than *J. regia (59)*. The same hybrid produced in France combines Phytophthora resistance and vigor (*53*). Specific combining ability can be an important factor in hybrid performance: Schuster *(54)* found that *J. regia* var. 'Franquette' produced progeny averaging 133 cm tall at age 3 years when pollinated by *J. nigra* var. 'Stabler', but when another black walnut tree was used as a pollen parent, the progeny were only 60 cm. tall.

Wright (*75*, p. 161) has pointed out that within a genus, species that can cross usually have distinct (often adjacent) ranges, while species that occupy the same sites in the same regions develop barriers to hybridization. *Juglans* seems to follow this pattern, with *J. nigra* and *J. cinerea* often growing together but apparently never crossing naturally, while all other walnut species (at least in the western hemisphere) are almost completely isolated. Thus, easy crossing might be expected among the morphologically similar North America Rhysocaryon walnuts. One example is the 'Royal' hybrid between *J. nigra* and *J. hindsii* produced by Burbank about 1888. This hybrid begins to bear viable seed by age 5 years, producing exceptionally large nuts (*68*). The hybrids are quite vigorous and recommended for development as timber areas (*27*).

As mentioned earlier, the only area where the ranges of Rhysocaryon walnuts overlap is in southwestern Oklahoma. Several trees that appear to be hybrids have been found in Comanche County, Okla.; their foliage strongly resembles *J. microcarpa* but seed size is intermediate between *J. microcarpa* and *J. nigra*, exceeding the maximum size specified for little walnuts (Funk, unpublished).

Manning (*41*) describes cultivated trees in Santiago, Chile, that may be hybrids between *J. nigra* and native South American Rhysocaryon walnuts, such as *J. venezuelensis* or *J. soratensis*.

A possible natural intersection hybrid between *J. nigra* and *J. cinerea* has been reported from southern Quebec (*22*), but since the fruit dimensions are well within the range of black walnut seed size, it seems prudent to be skeptical about this tree's hybridity. Soviet tree breeders have been active in walnut hybridization for more than 50 years. They have recorded some spectacular successes that deserve attention and attempts at verification by Western breeders. Among these are reports of 46-percent crossability in *J. nigra* x *J. mandshurica* and 16 percent for a cross between black walnut and mockernut hickory (*59*). Shchepot'ev (*58*) also reports a hybrid between black walnut and butternut and suggests that the cross is more easily made if vigorous young black walnut trees are used as the female parents.

Inheritance

McKay (*37*) found both leaflet shape and number in *Juglans regia* x *nigra* hybrids to be generally intermediate between values for the parent species. He postulates polygenic inheritance of these foliage traits and also of susceptibility to infection by walnut anthracnose, *Gnomonia leptostyla* (Fr. Ces. & deNot.).

IMPROVEMENT PROGRAMS

Objectives

The objectives of a black walnut breeding program will likely be somewhat different from those for other forest trees. The continuing strong demand and high prices paid for walnut veneer timber justify the use of more intensive culture than is or will be practical in field plantings of most other forest species. And the possibility of selling nuts as a cash crop offers a chance to recover a part of plantation establishment costs well before the trees have grown to merchantable saw log or veneer timber size.

In light of these circumstances, a *Juglans nigra* breeding program might include these objectives, approximately in this order: (1)

Climatic adaptation, (2) vigor and growth rate, (3) form, (4) fecundity, (5) pest resistance. A separate or additional objective may be breeding of special-purpose strains, such as for planting on droughty sites or on poorly aerated soils.

Specific Traits

Nursery Selection

It should be possible to select in the nursery for some aspects of climatic adaptation such as winterhardiness—undoubtedly natural selection will operate to some extent. Selection for drought resistance in some seasons could be done in the nursery by deliberately withholding irrigation water during the growing season and by diverting natural rainfall from test beds. In such tests it is important to remember that trees in the center of nursery beds are subject to more intense competition than those along the edge.

Edge effects must also be considered in any attempt to select for growth rate in the nursery. Walnut seedlings should be grown no closer than 1 foot apart if they are to be considered free to grow during the first year in the nursery bed. Seed-size effects are also important (*4*, *9*); unless enough seed are available to allow cracking a random sample to determine relative kernel size, seedlings should be grown a second year in the nursery in order to calculate relative growth rate (*61*).

Also, if no pesticides are used, it should be practical to do some screening in the nursery for resistance to ubiquitous diseases such as walnut anthracnose.

Selection in Plantations

Because they are even-aged and regularly spaced, plantations offer an excellent opportunity to select for rapid growth rate. Further, planted stands are more likely to be located on relatively uniform sites than are natural stands.

Logically, plantations are the optimum place to select for traits that will be important in the plantation-grown trees to be bred. This point holds particularly true for form and apical dominance. The inherent ability of trees to grow straight and free from forks should be best expressed in widespread, even-aged stands in which the individual stems have not been subjected to close competition and "training." Self-pruning tendency is not likely to be important in intensively cultured plantations and need not be considered in selection.

Many walnuts growing naturally as individual trees or in small groups escape attack by damaging insects and diseases. Thus, mass selection for pest resistance in natural stands is likely to prove misleading. But in plantations, the opportunity for epidemic attack is optimum, and any unaffected individuals have a good chance of being truly resistant rather than mere escapees.

Plantations also provide a good opportunity to select for fecundity since barrenness in scattered forest trees may be more a result of insufficient pollination than inherent infertility.

Selection in Natural Stands

Selection of mature trees in natural stands comes closest to assuring climatic adaptation and resistance to infrequent or cyclical attacks by pests. Sometimes, especially in the limestone areas of Indiana, Kentucky, and Tennessee, rather well-stocked stands of pure walnut have been created by clearing all other species from a mixed woods to make pasture. The walnut trees have been left behind deliberately to provide shade and valuable timber, and if the other trees were removed while the walnuts were still young enough and numerous enough, there is just as good an opportunity to select for growth and form characteristics as there is in plantations.

It is tempting to take increment cores from potential walnut selections, not only to determine age, but also to assess wood color and sapwood/heartwood ratio. But the severe defect often induced by boring walnut (*11*) and the well-developed techniques for curing veneer and lumber so as to make the sapwood take up heartwood color combine to make increment boring unwise and often unnecessary.

Mating Systems

Although most walnuts are probably technically self-fertile (*25*), the natural outcrossing tendency resulting from dichogamy gives the breeder a good opportunity to prevent excessive inbreeding. It is even conceivable that protandrous and protogynous clones or lines with good combining ability could be matched so as to produce reciprocal hybrids with all trees serving as both male and female parents—but this possibility is too unlikely to be important in present planning.

Development of specialized highly inbred varieties seems particularly inappropriate in long-lived plants such as walnuts that must survive and thrive over changing seasons and fluctuations in climatic and pest cycles. In his discussion of plant breeding systems, Andrus (*1*) reemphasizes the continuing advantages of maintaining a balanced genic system, well adapted to the environment and with sufficient flexibility to maintain phenotypic stability in the face of variable external conditions. Such an approach corresponds comfortably with reality since the delay of at least a few years while waiting for seedlings to flower and fruit, plus the need to wait until the test plantations reach about half-rotation age before making confident growth evaluations, almost completely preclude the possibility of developing inbred parental lines.

At least two breeding methods seem to offer good prospects for the near future. For simple traits suspected of having reasonably high heritability, such as flat branch angle or disease resistance, mass selection to create "pure line" varieties maintained by intrafamily crossing may prove effective. Progeny testing will be necessary unless and until good heritability is demonstrated and efficient early selection techniques can be developed.

Some sort of recurrent selection program will probably be required to produce hybrids superior for complex traits such as vigor and fecundity since mass selection for growth rate in hardwoods does not look promising. The opportunities for selection in natural walnut stands are particularly poor, and we should not expect to make rapid progress along these lines.

Seed Orchard Design and Management

Black walnut is unusally well suited to growing in an orchard that combines seed production and progeny testing. The intensive culture and wide spacing recommended for young walnut plantations (*6*, *10*, *29*) are similar to conventional orchard management practices. Also, since the walnut seed falls promptly after it ripens, it isn't necessary to maintain low crowns as in orchards where fruit must be picked by hand. Therefore, walnut seed orchards can be pruned to a moderate height, say 9 feet, allowing easy maneuvering of equipment beneath the trees and also producing a salable log.

The desirability of combining orchards and progeny tests and the possibility that black walnut can be brought into bearing at a relatively early age make seedling seed orchards a good prospect. Until we have better heritability estimates for important traits, there seems to be little justification for establishing clonal orchards. It may be desirable to insert superior grafted varieties with known flowering patterns into young orchards to ensure an adequate supply of pollen both early and late in the blooming season. Orchards that are to be used as progeny tests must be located within the zone of seed use.

There is no possibility of complete protection against contamination by foreign pollen, but a 400-foot isolation strip should probably be considered as a minimum; a 1/2-mile strip would be better (*72*). Separating the orchard from forests of any kind also may help to reduce seed pilferage by squirrels.

Several details of walnut seed orchard management are covered in an earlier paper (*21*), but among these, irrigation practice seems to be especially important and worth mentioning here. For one thing, irrigation of young trees through May, June, and July will prolong their growing period and promote their reaching flowering size at an earlier age. After the trees begin to bear seed, adequate soil moisture is still important, since under normal conditions, nut size is directly related to current season's growth of a tree (*13*). Recent papers by Holmsgaard and Olsen (*26*) working with beech, and Sharp and Sprague (*57*) studying white oaks, present something of a dilemma since they suggest that drought may be beneficial while the following year's flower buds are forming. Thus, May-June irrigation may have to be balanced between the benefits of plenty of water for the current year's seed crop and restricted soil moisture for the following year's flowering. It may be possible to develop a satisfactory watering schedule that shifts abruptly from low to high soil moisture at some time during the late spring. The cotyledons and embryo of the seed develop much later in the season, only 4 to 5 weeks before the nuts mature, and deficient soil moisture can lead to poor filling of the kernels and also delay maturing of the seed (*13*, *3*). Thus, irrigation during August and September can also be important since these months often include long dry spells.

Research Needs

Much of the needed research in black walnut is similar to that required for many other species. For instance, the need for improved selection standards is common in forest tree breeding and includes development of early tests and correlation of morphological, biochemical, and physiological traits. Similarly, flower induction studies receive high priority in breeding programs for all plants with long generation intervals. But there are some distinctive problems connected with future genetic improvement in *Juglans*. For one, we need much more efficient means of producing own-rooted clones of selected trees. Also, the almost complete sterility of many hybrids presents an awkward barrier to breeding progress. And we need much more information that can only be provided by controlled crossing and detailed genetic analyses. In contrast, since both fast- and slow-grown walnut seem well suited to most manufacturing processes (*19*), there may not be a great need for research in the genetics of wood quality characteristics.

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Reference Abstract

Funk, David T.

1970. Genetics of Black walnut (*Juglans nigra*). U.S. Dep. Agric., For. Serv. Res. Pap. WO–10, 13 p.

Characteristics of black walnut including reproductive development, seed handling and nursery practice, cytogenetics, natural variation, hybridization, and inheritance are reviewed as they apply genetic improvements of the species. A breeding program including objectives, selection, mating systems, and seed orchard design and management are suggested.